Development of a New Implant Primary Stability Parameter: Insertion Torque Revisited

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ABSTRACT

Purpose: The aims of the study are to introduce a new parameter to measure primary stability and to evaluate the possible correlations between this parameter and bone density, initial bone-to-implant contact (IBIC), Resonance Frequency Analysis (RFA), and peak insertion torque (IT).

Material and Methods: The study was performed on three different types of fresh humid bovine bone: type I, type II, and type III. A total of 90 XiVE implants (30 per bone type) were used; implant insertion was performed with a calibrated maximum torque of 70 Ncm at predetermined 30 rpm. The IT data were recorded and exported as a curve; using a trapezoidal integration technique, the area underlying the curve was calculated: this area represents the variable torque work (VTW). Furthermore, peak IT and RFA were recorded; finally IBIC was calculated from histological specimens.

Results: Spearman correlation analysis of the entire sample reveals that VTW presents a significant ($p < .01$) positive correlation with bone density; a significant ($p < .05$) positive correlation with IBIC, and a significant ($p < .01$) positive correlation with all the other primary stability parameters. Spearman correlation analysis of the three different groups show that VTW presents a significant positive correlation with IT in all three types of bone; on the other hand, VTW shows a negative not significant correlation with RFA in bone I, a positive significant correlation in bone II, and a positive not significant correlation in bone III. Furthermore, VTW shows a negative significant correlation with IBIC in bone I and a positive significant correlation in bone II and III.

Conclusions: Within the limitations of an in vitro study, the VTW seems to be a promising parameter to measure implant primary stability.

KEY WORDS: dental implants, insertion torque, primary stability, variable torque work

INTRODUCTION

Primary stability is considered of paramount importance to achieve osteointegration. The introduction of immediate loading protocols requires a high degree of primary stability to assure the bone/implant/crown system, the indispensable stiffness necessary for a successful result. In presence of optimal implant primary stability, immediate loading technique demonstrated good results.[1]

Originally, the clinicians used to evaluate the primary stability by percussion test or by their own perception during the implant insertion procedure; to avoid mistakes, different methods to objectively evaluate primary stability were proposed: in particular peak insertion torque (IT) and Resonance Frequency Analysis (RFA) are the most used worldwide.[2] The determination of the first can be done by a torque gauge incorporated within the drilling unit but even more often by means of manual wrench ratchets, which are more imprecise and subject to wear;[3] on the other hand, RFA is measured by an electronic device and a transducer tightened to the implant by a screw. Nevertheless, a recent paper showed that RFA and torque represent two different features of primary stability:[4] this difference can cause a contradictory evaluation of primary stability[5] and, as a consequence, can lead clinicians to a misinterpretation of primary stability measurement in their practice.

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For all these reasons, a new, more predictive method to evaluate primary stability seems to be necessary; the aims of this study in vitro are to introduce this new parameter and to evaluate the possible correlations with bone density, initial bone-to-implant contact (IBIC), and the already known RFA and peak IT.

MATERIALS AND METHODS

The study was performed on three different types of fresh humid bovine bone: type I, type II, and type III according with Lekholm and Zarb classification.[6] Bone density was determined before insertion by means of computerized tomography scans and it was confirmed by the evaluation of the drilling resistance during implant bed preparation. A further confirmation was obtained with subsequent histological analysis. Type I bone samples were composed by a completely cortical structure and were obtained from the tibial bone; type II samples presented a layer of 2–3 mm cortical bone with a cancellous structure inside and were obtained from the hip; type III samples presented a very thin (<1 mm) cortical layer with a cancellous structure inside and again were obtained from the hip. The bones were firmly attached to a base device.

For the study 3.4 × 11 mm XiVE® implants (Dentsply Friadent, Mannheim, Germany) were used: these implants are based on a cylindrical core with a self-tapping thread; the thread depth increases from the crestal region to the apex with the thread pitch remaining equal; the external diameter remains constant. Thirty implants per bone type were inserted; therefore, a total of 90 implants were used.

The sites were prepared following the protocol provided by the manufacturer: the pilot drill of 2 mm was first used to proper depth, then twist drills of 2 mm and 3.4 mm were used. The crestal twist drills were used with a 2-mm depth in type III bone, with a 4-mm depth in type II bone, and with a 6-mm depth in type I bone. A 6-mm tapping was also performed in type I bone.

After site preparation, the implant was inserted by means of electronic surgical unit (FRIOS Unit E®, W&H Dentalwerk GmbH, Buermoos, Austria) with a calibrated maximum torque of 70 Ncm at predetermined 30 rpm.

During implant insertion, the IT data were recorded by the surgical unit and stored in an electronic card; data were then exported as a curve (Figure 1). After that, data were processed by a software developed on purpose by an informatics lab: using a trapezoidal integration technique the area underlying the curve or more simply its integral was calculated (Figure 2). This area represents the variable torque work (VTW) and is still expressed in Ncm: the predetermined constant rotational speed (30 rpm for all specimens) allows to assume time (abscissa in Figure 1) in radiants/second (30 rpm = 0.5rps = 180°/sec = π/sec), thus the area underlying the curve represents the VTW (work done = torque x angular displacement = T$d\theta$). Furthermore, after insertion, peak IT was recorded; finally RFA values expressed in ISQ were recorded by means of a transducer attached to the implant via a screw and a frequency response analyzer (Osstell Mentor® Device, Integration Diagnostic AB, Sävedalen, Sweden) with the average of two measurements performed with the probe in two perpendicular directions.

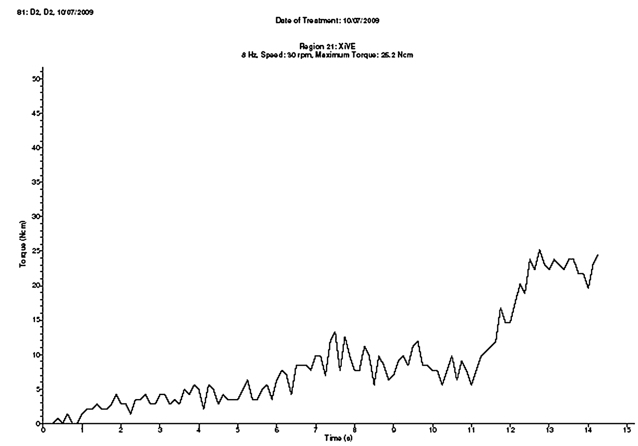

Figure 1 Insertion torque data exported as a curve.

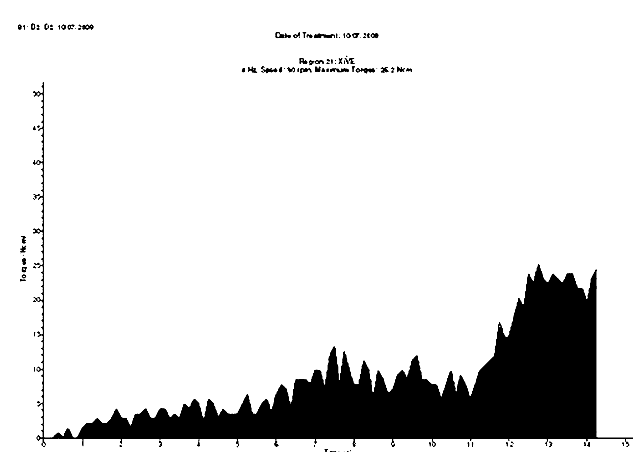

Figure 2 Integral of the curve.

Processing of Specimens

In all implants, immediately after insertion, the retrieval had been carried out with a 5-mm trephine bur, and the implants and the surrounding tissues were stored immediately in 10% buffered formalin and processed to obtain thin ground sections with the Precise 1 Automated System (Assing, Rome, Italy).[7] The specimens were dehydrated in an ascending series of alcohol rinses and embedded in a glycol methacrylate resin (Technovit 7200 VLC, Kulzer, Wehrheim, Germany). After polymerization, the specimens were sectioned longitudinally along the major axis of the implant with a high-precision diamond disc at about 150 mm and ground down to about 30 mm. Three slides were obtained for each implant. The slides were stained with basic fuchsin and toluidine blue. A double staining with von Kossa and acid fuchsin was done to evaluate the degree of bone mineralization, and one slide, after polishing, was immersed in AgNO3 for 30 minutes and exposed to sunlight; the slides were then washed under tap water, dried, and immersed in basic fuchsin for 5 minutes, and then washed and mounted.

Histomorphometry

Histomorphometry of IBIC was carried out using a light microscope (Laborlux S, Leitz, Wetzlar, Germany) connected to a high-resolution video camera (3CCD, JVC® KYF55B, JVCs, Yokohama, Japan) and interfaced to a monitor and personal computer (Intel® Pentium III 1200 MMX, Intels, Santa Clara, CA, USA). This optical system was associated with a digitizing pad (Matrix Vision GmbH, Oppenweiler, Germany) and a histometry software package with image capturing capabilities (Image-Pro Plus 4.5, Media Cybernetics Inc., Immagini & Computer Snc, Milano, Italy).

STATISTICAL ANALYSIS

After a descriptive data analysis, Kolmogorov–Smirnov test was used to test the distributive normality. Mann–Whitney and Kruskal–Wallis tests were used to compare mean values. Spearman tests were used to explore possible association between the studied variables. A p value <0.05 was considered significant.

RESULTS

The insertion procedure was performed without any particular problem; considering that all the implants were 11 mm long and that they were inserted at the same speed, each implant reached its final position in the same amount of time.

Table 1 shows mean values, standard deviation, and range of each single parameter recorded of all 90 implants together.

Spearman correlation analysis of the entire sample reveals that all the primary stability parameters recorded present a significant ($p < .01$) positive correlation with bone density: IT 0.871; RFA 0.423; VTW 0.411 (where −1 means perfect negative correlation and 1 perfect positive correlation). The same analysis shows that a weak not significant positive correlation can be found between IBIC and bone density (0.128), and that a significant ($p < .05$) positive correlation can be noticed between IBIC and all the primary stability parameters recorded (IT 0.317; RFA 0.235; VTW 0.266). A significant ($p < .01$) positive correlation was found between VTW and all the other primary stability parameters: IT 0.739; RFA 0.425. Finally a positive significant ($p < .01$) correlation appears between IT and RFA (0.575).

Tables 2, 3, and 4 present mean values, standard deviation, and range of each single parameter recorded for the three groups (bone type I, bone type II, bone type III).

Tables 5, 6, and 7 show the results of Spearman analysis of the three different groups: VTW presents a significant positive correlation with IT in all three types of bone; on the other hand, VTW shows a negative not significant correlation with RFA in bone I, a positive

TABLE 1 Mean, Standard Deviation, and Range of the Recorded Parameters for All 90 Implants

	Minimum	Maximum	Mean	Standard Deviation
Variable torque work	215.60	3721.90	976.55	541.17
Torque max	5	70	38.76	22.87
Resonance frequency analysis	66	90	79.66	5.46
Initial bone-to-implant contact	1.1	31.4	14.05	6.57

TABLE 2 Mean, Standard Deviation, and Range of the Recorded Parameters for Bone Type I

	Minimum	Maximum	Mean	Standard Deviation
Variable torque work	294.7	3721.9	1195.45	626.37
Torque max	27	70	63.16	13.25
Resonance frequency analysis	68	90	82.97	5.22
Initial bone-to-implant contact	1.1	23.7	13.78	5.8

TABLE 3 Mean, Standard Deviation, and Range of the Recorded Parameters for Bone Type II

	Minimum	Maximum	Mean	Standard Deviation
Variable torque work	509.6	2454.2	1089.01	463.05
Torque max	15	70	33	12.94
Resonance frequency analysis	66	87	78.72	5.96
Initial bone-to-implant contact	1.9	31.4	16.73	7.29

significant correlation in bone II and a positive not significant correlation in bone III. Furthermore, VTW shows a negative significant correlation with IBIC in bone I and a positive significant correlation in bone II and III. Finally RFA and IT present a negative not significant correlation in bone I and a positive significant correlation in bone II and III.

DISCUSSION

The introduction and spread of immediate loading technique aroused great interest about implant primary stability and its measurement; the methods proposed so far were object of several investigations, but the results are not yet convincing.[2] If RFA was considered very reliable

TABLE 4 Mean, Standard Deviation, and Range of the Recorded Parameters for Bone Type III

	Minimum	Maximum	Mean	Standard Deviation
Variable torque work	215.6	2154.6	659.50	354.14
Torque max	5	36	17.75	7.23
Resonance frequency analysis	70	84	77.32	3.40
Initial bone-to-implant contact	1.3	26.5	11.80	5.76

TABLE 5 Spearman Analysis Results of the Recorded Parameters for Bone Type I

	IT	RFA	VTW	IBIC
VTW	0.407 ($p < .05$)	−0.065	—	−0.391 ($p < .05$)
IBIC	−0.047	−0.173	−0.391 ($p < .05$)	—
IT	—	−0.189	0.407 ($p < .05$)	−0.047

VTW = variable torque work; IBIC = initial bone-to-implant contact; IT = insertion torque; RFA = resonance frequency analysis.

TABLE 6 Spearman Analysis Results of the Recorded Parameters for Bone Type II

	IT	RFA	VTW	IBIC
VTW	0.890 ($p < .01$)	0.519 ($p < .01$)	—	0.438 ($p < .05$)
IBIC	0.621 ($p < .01$)	0.510 ($p < .05$)	0.438 ($p < .05$)	—
IT	—	0.655 ($p < .01$)	0.890 ($p < .01$)	0.621 ($p < .01$)

VTW = variable torque work; IBIC = initial bone-to-implant contact; IT = insertion torque; RFA = resonance frequency analysis.

by some authors[8] and inconclusive by others,[9] the IT is measured either with highly sensitive instruments like electronic probes inserted in the low-speed insertion device[5,10] or with not so accurate manual wrench ratchets.[11,12] Furthermore, considerable confusion in the definition itself of IT can be found in scientific literature: some authors report the IT as a maximum value,[13] others as a mean value,[14] but in some papers it is difficult to understand which value was registered.[15] Finally, a recent paper demonstrated that RFA and torque represent two different features of primary stability, the first indicating the resistance to bending load, the latter indicating the resistance to shear forces:[4] this difference can cause a contradictory evaluation of primary stability[5] and, as a consequence, can disorient clinicians during the primary stability measurement in their clinical everyday practice. For all these reasons, a new and more reliable method for the primary stability determination appears to be necessary.

Commonly, peak IT is recorded, but this value can be obtained in several ways; for instance, Figure 3 shows the IT curve of an implant, placed in type I bone, that reached 70 Ncm with a sudden increase because of the friction of the crestal portion; on the other hand, Figure 4 shows the IT curve of another implant, inserted again in type I bone, that obtained the same peak value with a much more progressive gain. As a consequence, the same peak IT value expresses two extremely different clinical situations, the first representing a primary stability strongly dependent on a small portion of the implant, the latter showing a primary stability obtained by the whole implant body. To overcome these limitations, a new parameter was considered, the VTW; this parameter represents the integral of the IT curve recorded during implant insertion (Figure 2) and it appears more representative of the work required to insert an implant in the bone. Coming back to our example, the VTW of the first curve is 726 Ncm, whereas the VTW of the second is 1495 Ncm.

Tables 1 to 4 show the mean values of the primary stability parameters of all implants together and divided by bone type. It appears evident that, increasing the bone quality, all the parameters considered, and in particular IT, present higher values; nevertheless, if the IT shows a strong positive correlation with bone density (0.831), the VTW still presents a positive correlation but much weaker (0.411) showing that good primary stability can be obtained also in a softer bone and vice versa, as it can be often noticed in everyday practice. The difference between IT and VTW is confirmed also by the nonperfect positive correlation between the two parameters (0.739) indicating that high values of IT can be associated to lower VTW values as described in the previous examples (Figures 3–4).

TABLE 7 Spearman Analysis Results of the Recorded Parameters for Bone Type III

	IT	RFA	VTW	IBIC
VTW	0.837 ($p < .01$)	0.324	—	0.518 ($p < .01$)
IBIC	0.569 ($p < .01$)	0.213	0.518 ($p < .01$)	—
IT	—	0.543 ($p < .01$)	0.837 ($p < .01$)	0.569 ($p < .01$)

VTW = variable torque work; IBIC = initial bone-to-implant contact; IT = insertion torque; RFA = resonance frequency analysis.

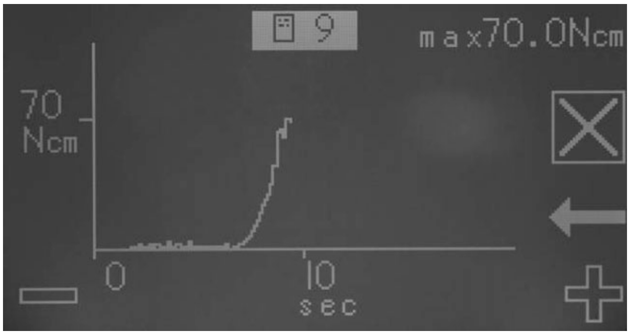

Figure 3 Insertion torque curve showed by the surgical unit (example 1).

The only partial positive correlation between RFA and IT (0.575) and between RFA and VTW (0.425) seems to confirm that RFA can not be considered a substitute for IT in the evaluation of the implant primary stability; the analysis of the correlation between these parameters in the different bone type groups is a further confirmation of this thesis: RFA and IT are negatively correlated in type I bone, positively and significantly correlated in type II and type III bone; RFA and VTW are negatively correlated in type I bone, positively and significantly correlated in type II, and positively but nonsignificantly correlated in type III bone. The complete absence of a linearity in the correlation between the parameters analyzed induces to believe that they actually measure different features of primary stability.[4]

The last important aim of the present study was to understand if primary stability is correlated to IBIC, namely the percentage of bone in contact with the titanium surface of the implant when the osteointegration process is not yet started. Immediately after surgery, the IBIC could be considered the "mechanical maker" of primary stability[16] and it was supposed that a strong correlation should be found between IBIC and primary stability parameters (RFA and IT); however, studies conducted on animals and fresh human cadavers failed to confirm this supposition.[9,17] The present study seems to confirm these results: the whole sample presents a significant ($p < .05$) positive correlation between IBIC and all the primary stability parameters recorded, but analyzing the different bone type groups, it can be noticed that IT and IBIC are negatively correlated in type I bone, positively and significantly correlated in type II and again in type III, but with a slightly weaker Pearson index. RFA and IBIC are negatively correlated in type I bone, positively and significantly correlated in type II, positively but not significantly correlated in type III. On the other hand, VTW and IBIC seem to present more linear results, being negatively and significantly correlated in type I bone, positively and significantly correlated in type II and in type III with a stronger Pearson index in the latest.

If it is quite easy to understand that a bigger bone-to-implant contact is correlated with a better primary stability in type II and type III, the negative correlation between IBIC and all the primary stability parameters analyzed in type I may seem inexplicable, but it is very likely that this phenomenon can be explained by the very low elasticity of cortical bone and by the use of tapping necessary to insert the implants in this bone group. When the implants are inserted with a perfect congruency between the threads and the bone preparation (Figure 5), the bone-to-implant contact is large, but the primary stability parameters are lower; vice versa when there is no congruence between threads and preparation (Figure 6), the bone-to-implant contact is small, but the primary stability parameters are higher.

Figure 4 Insertion torque curve showed by the surgical unit (example 2).

Figure 5 Histological specimen (example 1).

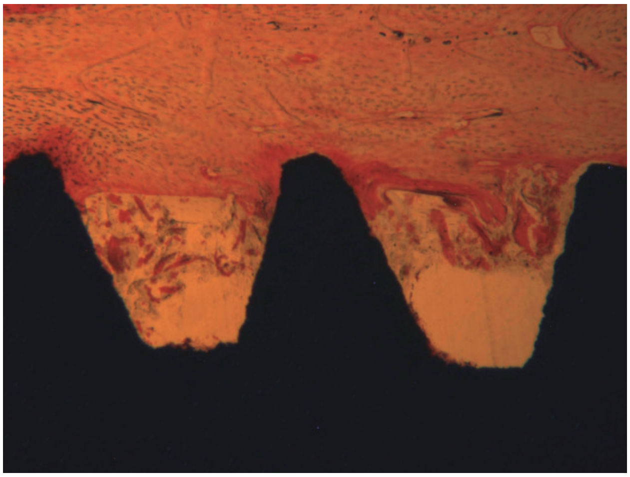

Figure 6 Histological specimen (example 2).

This difference in the congruency between the threads and the bone preparation shown by the histological samples could also explain some of the unexpected data presented in Table 2: in fact, implants with a good congruency between the threads and the bone preparation presented a low VTW; on the other hand, implants with low congruency showed high VTW values: this behavior resulted in a low mean value and a high standard deviation (50%) of VTW for implants inserted in type I bone. Furthermore, implants placed in type I bone showing histologic sections like those presented in Figure 6 determined a mean IBIC smaller than implants inserted in type II bone; on the other hand, implants placed in type I bone showing histologic sections like those presented in Figure 5 determined very low minimum VTW values.

The statistical significance of the correlation between IBIC and VTW in all the bone type groups seems to indicate that this new parameter could be more indicative of the clinical situation and more reliable in the measurement of primary stability than other systems already in use; further clinical studies are necessary to confirm these results.

CONCLUSIONS

Within the limitations of an in vitro study, the significant correlation between VTW and IBIC in all bone type groups suggests that VTW is a promising parameter to measure implant primary stability. Furthermore, the only partial correlation between this parameter and bone quality explains the clinical observation of the possibility of obtaining good primary stability also in softer bone.

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